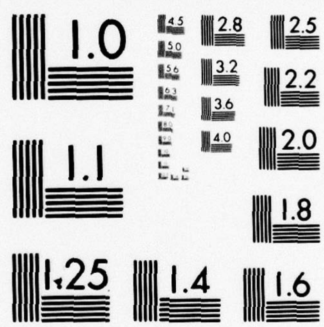
AD-A079 559 AEROSPACE MEDICAL RESEARCH LAB WRIGHT-PATTERSON AFB OH F/G 6/19
QUANTIFIABLE EFFECTS OF NOISE ON HUMANS,(U)
JAN 80 D L JOHNSON
UNCLASSIFIED AMRL-TR-79-18 NL

1 OF 1
AD A
079559

END
DATE
FILMED
2 — 80
DDC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU

AD A079559

DDC FILE COPY

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

LEVEL

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: AMRL-TR-79-18 (14)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): QUANTIFIABLE EFFECTS OF NOISE ON HUMANS (6)		5. TYPE OF REPORT & PERIOD COVERED: Oral Presentation
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Daniel L. Johnson (10)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wrignt-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62202F (16) 7231-08-AA (17) 08
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE: (11) Jan [redacted] 80
		13. NUMBER OF PAGES: 42 Pages
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 42		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at the American Bar Association National Institute in Houston, Texas on 6-7 April 1979.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Environmental Noise
Noise Induced Hearing Loss
Speech Interference
Workman's Compensation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Quantifiable effects of noise are defined as those effects that demonstrate both a clear causal relationship, and also an increase of severity of the effect with the magnitude of the noise exposure. While possible noise effects, such as elevated blood pressure and sleep interference, are discussed, a rationale is given for not considering these effects as quantifiable. The three quantifiable effects of noise are identified. These are induced hearing loss, speech/activity interference, and general community response. Measurement and evaluation of each of these effects are discussed. Recommendations and exceptions to evaluating the — over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

009 850

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT

environmental effects of noise are provided. Although the author recognizes the occasional need of other noise descriptors, the basic descriptor promoted by the EPA and accepted by the Department of Defense, the Day Night Sound Level, is recommended for measuring environmental noise. This measure provides a reasonable assessment of the three quantifiable effects for most types of environmental noises.

Accession For	
NTIS GRA&I	☑
DDC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

DDC LITE COPY

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

QUANTIFIABLE EFFECTS OF NOISE ON HUMANS

Introduction

Noise can interfere with an individuals activities, disturb him or even effect his hearing. While man has attempted to control some types of noise as early as the time of the Roman empire,[1] the event of the powered machine, gunpowder, modern transportation systems, and the densely populated cities have combined to result in increasing noise exposures of the individual. In fact, there is a good enough relationship between urban population density and noise level that population density is being suggested as a method for estimating background noise levels.[2]

In this paper, an attempt will be made to evaluate the effects of this present state of noise exposure. But as the title indicates, the focus will be on quantifiable effects. The three main effects of environmental noise are noise induced hearing loss, speech/activity interference, and general community response. The selection of these three effects is not a trivial question. For this reason, the rationale for selecting these effects and not others is addressed in the next section. Then a section on each of the three quantifiable effects is given. Finally, a discussion and conclusion is provided that summarizes the advice that I feel would be useful to those who are not overly familiar with the effects of noise. I realize that this paper is not going to make you an expert in noise, but I reference where more information is available.

Selection of the Quantifiable Effects of Noise on Humans

In order for a specific noise effect to be quantifiable, two basic elements need to be present. First, a cause and effect relationship needs

to be established. Second, there must be a correlation between the magnitude of a measurable noise exposure and the severity of the effect.

The first quantifiable effect, noise induced hearing loss, has both of those elements. With respect to noise induced hearing loss, we know by experience that one extremely loud noise can cause a permanent change in hearing ability. We can further verify such changes in animals by looking at hair cells of the inner ear damaged by noise exposures. This is backed up by many studies which clearly show differences in the hearing levels of workers exposed to different levels of noise.

With respect to community response, the same holds true. Just run up a jet engine for the first time next to a residential area and watch the reaction. Numerous social surveys verify this reaction and provide us a reasonable relation between such reaction and the amount of noise.

Activity interference, especially with respect to oral communication, is the third effect. Surely every reader has experienced this at one time or another. Laboratory studies provide definitive information on the increase of such interference with increased noise exposure.

Sleep interference can also be clearly demonstrated. What is not quite so clear, however, is the good correlation between the magnitude of a measurable noise exposure and the severity of the interference. Measurable noise exposure is emphasized because certainly I don't want to imply that louder noises do not interfere more with sleep. But when noise consists of various patterns of time and intensity, a single measure that encompasses most of the reasonable situations is difficult to obtain. Perhaps the equivalent sound level discussed later gives a reasonable estimate of the adverse effect, but this has not been fully established at this time. Lucas has provided a good summary of the studies of sleep interference from noise and his work should be consulted further.[3]

Possible non-auditory effects of noise have also been studied in recent years. While there have been a few potential findings based on high level exposures to humans or on animal experimentation, clear evidence that noise produces long term health effects has not been established. Not all researchers, however, agree with this last statement and there is an ongoing debate as to non-auditory effects.

Since such non-auditory effects are so controversial, it is useful to provide three different quotes on the subject that backup my statement that the non-auditory effects of noise have not been clearly established. For instance, referencing non-auditory noise the EPA Criteria Document concludes:

> "Noise can elicit many different physiological responses. However, no clear evidence exists indicating that the continued activation of these responses leads to irreversible changes and permanent health effects. Sound of sufficient intensity can cause pain to the auditory systems. Except for those persons with poorly designed hearing aids, such intense exposures should not normally be encountered in the non-occupational environment. Noise can also effect the equilibrium of man, but the scarce data available indicates that the intensities required must be quite high or similar to the intensities that produce pain."[4]

An even more recent assessment of the current state of knowledge on non-auditory effects of noise is contained in the Handbook of Noise Control[4] in the introductory paragraph of a chapter on Physiological Effects of Noise by Dr. William Burns.

> This chapter discusses the physiological reactions of the human body to noise; the effects on the hearing mechanism and psychological effects are described in Chaps. 8 and 16,

respectively. Knowledge in this field has not kept pace with advances in knowledge of the relation between noise and hearing. Studies of physiological effects contain difficulties of observation and interpretation. Where human laboratory studies are used, projection to real life situations may be misleading. Studies on lower mammals may be complicated by significant species differences compared with humans; and the effects of magnitude of the stimulus in animal experiments, compared with that conceivably sustained in real life in human exposure, must be considered. In field studies of real human situations, adequately controlled conditions may be unattainable, so that results deriving from some other factor in the total environment of the subjects may be incorrectly attributed to noise. All of these considerations enjoin caution in the acceptance of conclusions of any study in this field.

Kryter has also recently made detailed and objective surveys of the literature and it is appropriate to state the conclusions. In work supported by the U.S. EPA, Kryter concludes:[5]

In spite of the very large gaps in our knowledge and the existence of some apparently conflicting research results, the following conclusions are put forth, with, of course, the usual admonition that more research is needed before they can be accepted with great confidence.

1. There is no likely damage risk to a person from the possible unconditioned stress responses to noise that are mediated by the autonomic system.

2. Noise may often be concomitant with danger and adverse social-environmental factors that are more important than the noise itself as a cause of apparent greater incidences of various physical and psychological disease and accidents in industry.

3. Autonomic system stress responses could conceivably be a contributing factor to ill health in some persons as the result of noise in their living environment directly interfering with auditory communications and sleep, and, thereby, creating the feelings of annoyance and anger that serve as the direct cause of the stress responses.

On the other hand, for a good summary from the advocates of such nonauditory effects the reader is referred to the work of Welch.[6]

Upon reviewing both sides of the argument, I see as the basic cause of disagreement that most non-auditory research has not found clear cause and effect relationships. For instance, there are some studies that have shown that blood pressures of workers in noisy industries are higher than the blood pressures in the general populations. What such studies have not shown is that the noise is the cause of the high blood pressure. The high blood pressure could just as well be due to vibration, dust, the danger of moving machinery, etc., or some combination of these. One can reasonably assert that noise is a by-product of those kinds of jobs that probably do cause more stress. Remember, we can demonstrate that noise can cause permanent changes to the ear; but we have no similar data for blood pressure. Thus we can only make a conjecture that there might be a cause and effect relation. Such a relation might be shown if we could find two groups of people identical in all ways except for noise exposure. Unfortunately, such a situation has not been found. Until such proof is forthcoming, I believe that such possible effects must be ignored in the current planning or decision making process.

I say this so positively because it is my opinion that the problem of blood pressure is too important for mistakes. It would be unfortunate if a large effort was made to reduce noise in industry only to find later that high blood pressure is due to other factors. What is needed at this time is more research on non-auditory effects, not money spent on noise control. Besides, there is enough information provided by the quantifiable effects to justify reducing man's noise exposure. Before discussing these effects; however, we need a method for describing noise exposure. Such a descriptor is in use and the rationale for its selection is provided in the next section.

Selection of the Descriptor of Noise Exposure

It has been often said that the effect of noise varies with respect to magnitude, frequency spectrum, and time pattern. Dr. von Gierke[7] has provided an excellent summary of the problem of selecting a single descriptor that adequately relates the complexities of noise exposure to the even more complex problem of defining health and well being. The reader is encouraged to read both von Gierke's article and the EPA "levels" document[8] for a more detailed discussion than will be presented here.

The choice of a noise descriptor by the EPA was based on several considerations.[9] Briefly these were: (1) the measure should be applicable over long periods of time, (2) it should correlate with non-noise effects on humans, (3) it should be simple, practical, and unambiguous, (4) it should be measurable with existing equipment, (5) it should be determined from physical events, and (6) it should be closely related to existing methods.

Correlating the three quantifiable effects with a single descriptor fulfilling these considerations led to the selection of the long-term average sound level, called equivalent sound level (L_{eq}), as the best means for describing the magnitude and time pattern of the environmental noise. This equivalent sound level is the constant sound level which in a given situation and over the considered time period would expose the ear to the same amount of energy as does the actual time varying noise patterns.

Such a measure was already in use for aircraft noise and had been proposed for hearing loss by an international standard. It was shown in ref 8 that this equal energy concept can estimate the amount of activity interference. Most researchers recognize that the equal energy concept can be somewhat in error for specific time patterns. For instance, intermittent noise will cause less temporary hearing changes than continuous noise of the same energy. Nevertheless, the energy approach has proven to be a very reasonable simplification for most environmental noises.

With respect to the frequency of the noise, A-weighting was selected as the best procedure for relating all three quantifiable effects. An important point needs to be made here. There are better weightings than A-weighting for loudness and there is a better measure (the preferred speech interference level) to assess speech interference. A-weighting, however, is the best compromise for all three effects.

To account for the idea that community noise exposures do cause more of a problem at night (an idea that is more of a reasonable concept than a proven fact, hence not everyone agrees with it) a ten decibel penalty was added to the nighttime noises, nighttime defined as those 9 hours from 10 p.m. to 7 a.m. Using this penalty, the subsequent measure is called the day-night average sound level. The symbol is L_{dn}. While the use of

a symbol for an abbreviation is not quite proper, the common usage has been to call this measure L_{dn} in writing and to pronounce the letters L, D, N in oral speech instead of the abbreviation DNAL. In compliance with common usage, L_{dn} will be used in this paper.

To extend this measure over long time periods, the concept of a yearly L_{dn} based on an energy principle was proposed in the EPA "Levels Document."[10] I have heard criticisms that such averaging under predicts the affects from noise events that are seasonal or that last only a few days or weeks. Often, I expect, the critics visualize an arithmetic average instead of the energy average.

One needs to keep in mind that an 80 dB sound has 1000 times more energy than a 50 dB sound. An L_{dn} of 80 dB averaged on an energy basis with a L_{dn} of 50 dB results in a two day average of 77 dB. Thus, this energy averaging does give more focus to the high noise exposures. The implications of this on a yearly basis will be further discussed when annoyance is discussed.

Quantifying Noise Induced Hearing Loss

Aside from a few published incidents, most of the available information about the permanent effects of noise on humans is derived from occupational noise exposures. Thus, by necessity, the environmental effects of noise must be predicted from occupational noise data, which consist of 8 hours of relative steady noise for 5 days a week. Such studies of occupational data usually compare the hearing levels of noise exposed workers to the hearing levels of workers not noise exposed on the job. The difference in hearing levels is called Noise Induced Permanent Threshold Shift or simply NIPTS. More space will be given in this paper to noise induced hearing

loss than to the other two quantifiable effects. This does not imply that hearing loss is necessarily the more important effect, but instead, this emphasis is the result of the fact that I do more research and writing on noise induced hearing loss.

Figure 1 and Figure 2 illustrate more precisely what is meant by NIPTS. Using data from Robinson,[11] distributions of the two different populations with respect to hearing threshold level are shown in Figure 1. In one case, the population is not exposed to occupational noise of any significance and in the other case a daily exposure of 90 dB over 20 years is received. Figure 2 illustrates how differences in the two distributions might be evaluated. Notice that NIPTS is the difference between the hearing threshold level of the noise exposed ears and the hearing threshold level for the non-noise exposed ears for a given percentile level. Because these are made at one point in time (i.e. cross-section), the actual changes in individuals are not available. This would require longitudinal studies in which individual hearing levels are followed over many years, unfortunately such studies are not available. At the present time, the most comprehensive studies, those of Passchier-Vermeer,[12] and Robinson[11] and Baughn,[13] are all cross-sectional.

In support of the needs for a Criteria Document[1,14] for the Environmental Protection Agency, the work of Passchier-Vermeer, Robinson and Baughn were combined to produce one unified relationship between continuous noise exposure and hearing loss.[15] Of course, the resulting relationship is not perfect, but then it has been amply pointed out by many critics that there is no complete or perfect study. Nevertheless, the NIPTS values of the unified relation versus any one of the relationships predicted by Passchier-Vermeer, Baughn or Robinson, in general, were well within 5 dB of each other.

Table I provides a summary of the effects of noise on hearing using the arithmetic average of the data of Baughn, Passchier-Vermeer, and Robinson. Several measures are used for three different combinations of audiometric frequencies.

These measures are:

(1) Max NIPTS (90th Percentile). This is defined as the maximum value of NIPTS reached during 40 years of noise exposure after the age of 20 for the percentile designated, namely, the 90th. This parameter was used since Baughn's data at 4000 Hz showed more change at 10 years than at 40 years. This measure, thus, is an average of the most NIPTS predicted by any of the three investigators.

(2) NIPTS (90th percentile) at 10 years. The expected NIPTS after ten years of exposure during adult life for the hearing level not exceeded by 90% of the population.

(3) Average NIPTS. The gross average value of NIPTS obtained by averaging over a 40-year exposure duration and also over all the population percentiles. Note: This figure differs by only a couple of decibels from the median NIPTS value after 20 years of exposure. This measure was presented in order to estimate what happens to the entire distribution over the total 40-year exposure history.

(4) Hearing Risk. Hearing risk is defined as the difference between a noise exposed and a non-noise exposed group with respect to the percentage of people with a specified handicap. Whether a person exceeds this handicap or fence of 25 dB (re 1969 ANSI) is used is usally determined by averaging his hearing levels at several frequencies. Traditionally,

handicap is considered to start when a fence of 25 dB (re 1969 ANSI) is exceeded for the frequencies of 500 Hz, 1000 Hz and 2000 Hz. It is this measure that has been responsible for many critical statements with respect to the reliability of the data base. The use of Hearing Risk may be appropriate if one wants to determine the amount of compensation required by people exposed to noise. However, it does not presently lend itself to accurately describing the effects of noise on hearing because more precise knowledge of the nonoccupational hearing level than currently available is required.

In regard to Hearing Risk, note that the relation of the fence (25 dB AHL) to the hearing levels of the non-noise exposed population becomes critical. If the fence is at location A or E as seen in Figure 2 the Hearing Risk will be small. If, however, the fence is at B, the Hearing Risk will be a maximum. More realistically, the 25 dB (re ISO fence is located somewhere between C and D. Obviously, the value of the Hearing Risk obtained for fence C is clearly quite different than if fence D is used. Thus, the location of the fence with respect to the median of the non-noise exposed distribution is critical. Unfortunately, for most data bases, including the ones of Baughn, Robinson and Passchier-Vermeer, there is significant disagreement over where the non-noise exposed median should be in relation to the 25 dB ISO fence. This is why the simple use of NIPTS, as presented above, is preferred over the use of Hearing Risk.

Interpretation of the Data.

As stated previously, cross-section studies cannot describe the actual changes in individuals. When longitudinal studies are accomplished, they will undoubtedly show a greater NIPTS of 90% of the individuals exposed to a certain noise history than the NIPTS of the 90th percentile point of noise exposed populations. But it is still not clear which is the better measure for assessing the effect of noise on hearing.

When talking about individuals, the practical significance of many individual shifts, let's say from -10 dB to 0 dB, becomes hard to interpret. A typical question that always arises is, "Is a 5 dB shift from a hearing level of 40 to 45 dB more significant than a 10 dB shift from a hearing level of 5 to 15 dB?" Such distinctions require a value judgement that we are not in a position to make. On the other hand, use of cross-sectional data simplifies this problem, since use of a 90th percentile point or higher provides administrators and the courts, who finally must make the judgement as to what insult can be allowed, with a basis for their decision making. This relationship is both the most sensitive (the 90th percentile shows more change than a lower percentile) and the most significant (the assumption is that a 5 dB change in the hearing of a poor hearing individual is more significant than the same change in the hearing of a good hearing individual).

With these considerations in mind, let us focus on the difference between the 4000 Hz audiometric frequency and the traditional speech frequencies of 0.5, 1 and 2 kHz. From Table I, the relationship between the NIPTS of speech frequencies as well as 4000 Hz and noise exposure for the 90 percentile point can be seen. This is plotted on Figure 3. The key point to see in this

figure is that there is about a 12-15 dB difference between the NIPTS of the 4000 Hz frequency and the traditional speech frequencies. This 4000 Hz frequency, which appears to be the most sensitive of any audiometric frequency to the general environmental noise, was used by the published "levels document" of the EPA. It is easy to see that the biggest reason the levels document identifies 75 dBA for 8 hours as the necessary exposure level that will not produce significant hearing changes is the use of 4000 Hz. A simplistic approach is just to say that much of the difference between the 90 dBA of OSHA and the 75 dBA of the EPA levels document is the 15 dB difference caused by including 4000 Hz in the assessment. In Table I it is clear that some NIPTS is predicted for even 75 dB. For very narrow bands of noise that may be true, but for broad band noise, the better estimate of NIPTS at 75 dB at any percentile is probably zero. Table I has been revised somewhat and in work that I am doing for a national standard, no hearing loss is predicted for 75 dB. Recent studies of Temporary Threshold Shift verify that this is a reasonable modification since the threshold of temporary changes from broad band noise is between an A-weighted level of 75 dB to 80 dB.[17,18,19] The assumption is, of course, that if temporary changes do not occur, permanent changes cannot occur.

The original values of 75 dB were extrapolations from higher industrial exposures in any case. After careful review of the available data, I am convinced that the 75 decibel level is the right threshold for the "safe level" of environmental noise.

Of course, there are those who would say that trying to protect against a change in hearing in any part of the population at 4000 Hz is ridiculous.[20]

Maybe so, but usually such statements are made because economic and feasibility trade-offs are introduced too early in the decision making process. The 75 dB level identified in the "levels document" did not consider either economic or feasibility considerations.[8] These latter considerations may require that any public health standard which is enforceable by law (for example the OSHA standard) be different from longer range social goals. I would agree that it is very important to consider the costs of implementing any enforceable standard to the benefits gained. Such an analysis might show that 95 dB, not 90 dB, is a more reasonable occupational level for many industries in the immediate future. However, I firmly believe that the 75 dB level for 8 hours is the best approximation of a true "safe level." This 75 dB level serves as a baseline from which to deviate in order to establish levels that are temporarily reasonable.

There is another approach to environmental noise that is worth considering. The majority of the persons familiar with noise who read this paper will probably concur that either 85 decibels or 90 decibels is an appropriate occupational noise standard at present. However, to these readers I would like to ask, "Would you feel the same way if your family win their home or environment were exposed to similar levels due to traffic noise? Most of the people I know would answer in the negative. Yet my first experience with environmental noise concerned use of the OSHA standard in determining the safe noise levels of the passenger compartments in airplanes. The use of the OSHA standard for such decision was made in spite of the fact that the OSHA standard is not based on such environmental considerations. When the levels of such standards are promulgated as "safe" (no effect) instead of reasonable (the effects are balanced by technical feasibility and economics), such misuses of the OSHA standard will continue to occur.

Compensation

Before leaving the problem of noise induced hearing loss, it is fitting to discuss briefly the problem of compensation for occupational hearing loss. I'm convinced that there are some gross inequities in our compensation procedures at this time. Ginnold has provided a good review of the inequities due to the different administrative procedures of the various states.[21] In many states compensation for noise induced hearing loss is effectively excluded because noise just does not make a person completely deaf. However, the inequity that I would like to focus on is the one due to the age at which the monetary compensation of an individual is determined. The problem can best be illustrated by figure 4. In this figure, the predicted hearing levels of two males are depicted, both with hearing levels at the 90th percentile (90 percent of the people hear better) as determined by the 1960-62 PHS data.[22] In one case one of the individuals received a 10 year noise exposure of 95 dB from age 20 to age 30 while in the other case this same exposure is received from age 50 to age 60. Note that as best as we can predict with data available today, both individuals, on the average, would have the same hearing level at age 60. In addition, the early exposed individual is very likely to have a compensable hearing loss (above a 25 dB fence for the average of 500 Hz, 1000 Hz, 2000 Hz and 3000 Hz)[23] for a greater time during his life. So, do we compensate this early exposed individual more? No. In fact, the current compensation procedures will very likely not compensate this early exposed individual at all since many states require the compensation cases to be filed within one year of the termination of employment. At the age of 31 years the early exposed individual will not have exceeded the 25 dB fence! The problem, of course, is that there is

a very high relation between hearing level and age. The best solution is probably to make compensation payable based on several measurements during an individual's life. In lieu of this, one might argue that compensation payments should be determined only when a person reaches a specific age such as an age of 60 years.[24] In any case, I would refer you to reference 24 for further detail.

Quantification of Speech/Activity Interference

Certainly every reader has experienced the difficulty of talking to another person in a noisy situation. This difficulty can be quantified for every day speech and the relationships shown in figure 5 have been derived from laboratory experimentation.[25] In this figure, the relationship for the maximum distance between talkers and the noise level are given for different voice levels of the talker assuming 99 percent of the time the speech is understood. This figure should give one a clue to the way people might adapt their face to face communication in noisy situations. One way, of course, is to raise one's voice. The talker and listener might also move closer together. Less intelligibility can also be accepted, especially if the listener feels that he can ask the speaker to repeat parts or all of the speakers words. The speaker might also stop speaking during the more intense parts of a fluctuating background noise. Thus there are many ways to adjust to the noise in this situation. However, as the listener and the speaker, or speaking source, becomes more and more inflexible, this ability to adjust to the noise level is lost. For instance, in the classroom situation, the students usually do not have the option of moving closer to the teacher. In my own experience, the students are also reluctant to ask the teacher to repeat. Thus some of the ability to adjust to

different noise levels is lost and for this reason the same noise levels can be expected to impact a classroom situation to a greater extent than a casual conversation between two people. In the case of watching television, the situation is even more inflexible. The information flow from a television set will not temporarily halt nor will it repeat itself in order to compensate for intermittent noise interruptions. The volume of the television can be raised, of course, but even this adjustment is usually less than perfect since the television may well be unacceptably loud during the quiet times of an intermittent noise. Finally, there are times that there is no flexibility at all. An announcement on a public address system is such an example.

In summary, the effect of noise on communication is complex and each specific situation requires an individualistic approach. Nevertheless, it is clear, the greater the equivalent noise level, the greater will be the problem of establishing satisfactory communication through any of the techniques described earlier. Furthermore, two other facts should be kept in mind. First, it is clear that people will accept different amounts of communication difficulty dependent on the situation. Use of a raised voice might be acceptable to aircraft passengers, but completely unacceptable in the home environment. The need for a relaxed conversation in a typical living room thus dictates a background noise level no higher than 45 dB while a level of 75 dB can be acceptable in an aircraft and 100 dB acceptable in a disco establishment. In the latter case, one communicates by shouting in each other's ear. The second consideration is that not everyone has perfect hearing, especially at the higher frequencies. It has been clearly

demonstrated that while such individuals may be reasonably normal with respect to the ability to understand speech in quiet, they have much more difficulty in understanding speech in noise.[26] A glance of figure C-1 of reference (8) demonstrates that the majority of the American males over the age of 40 will have this problem (defining the threshold of this problem as a 25 dB loss at 4000 Hz). The effect of this will be to reduce the distances that are shown in figure 5.

One could go even further to predict that older people would have a harder time understanding the words of modern music since the background music acts as noise. Somewhat with tongue in cheek, I might propose that perhaps this is part of a basis of a generation gap.

Annoyance/Community Response

As has been discussed in the preceding section, noise interferes with speech and other verbal activities. Although the effects cannot be accurately quantified, noise also interferes with sleep, relaxation, mental concentration, and etc. While such interference can be expected to impact an exposed population, the impact is not always constant. Mental states change, attitudes toward specific noise sources will vary. Dr. von Gierke accurately states with respect to such parameters such as attitude toward noise source, familiarity with noise, general psychological state, etc:

> These parameters are not constants; they can change for each individual from day to day and undergo changes during his lifetime; they can change from individual to individual, from country to country, and they might change with time as the value systems of societies, their environmental awareness, their appreciation of privacy and their economic situation changes.

In spite of these potential influences, it appears possible to specify for today's populations levels of environmental noise which do not significantly interfere with their activities and degrade their overall well being.[27]

The key to establishing such levels is public opinion studies. Consolidation of the data of such surveys has been done by Schultz[28] and his results are shown in figure 6. In this figure the percent of the respondents who responded that they were highly annoyed is related to the expected or measured outside environmental noise exposure of the residential area in which they live. As can be seen, the percentage of Highly Annoyed (% HA) clearly increases with the day night average sound level (L_{dn}). This provides a useful long-term adverse response of people to noise.

It is appropriate to consider how this % HA is determined. Social surveys are conducted such that as much as possible, the response of living in a certain long-term environment is obtained, and not the response from isolated events. Somewhere in the questioning the respondents are asked to rate how annoying is the noise on a scale, for example from one to seven. One might be described as "not annoyed," two might be described as "a little annoyed," while seven might be titled "severely or highly annoyed." As you might expect, the descriptors used for the steps on the scale as well as the number of steps on the scale vary from survey to survey. But in the Schultz synthesis of figure 7, only the people who responded in the top 27 to 29% of the scale (the top 2 categories of a 7 step scale) were considered highly annoyed. Adjustments were made to

other scales to approximate the results of a 7 step scale. If a respondent felt only moderately annoyed, he or she probably would not be counted. Thus the relationship shown in figure 6 is only an indicator of the total high annoyance caused by the stated noise exposures.

The reasons that an individual might mark the top part of a scale can also be expected to vary. Interference with sleep might be the deciding factor for one person while a strong dislike of the predominate noise source might be the deciding factor of another. In any case, the resulting information, imperfect as it is, results in a useful tool to assess the overall effect of Community Noise. The term "Highly Annoyed" has been criticized as too weak. People who make regulations might like to have a term with more punch. We are annoyed by many problems, so what is so special about noise? Unfortunately, or perhaps fortunately, scientific evidence does not support using stronger words. Nevertheless, the reaction to noise can be related to other problems in society. Figure 7 shows the clear impact of noise level on the reasons why a person might move. As the L_{dn} increases from 55 dB to 75 dB, noise becomes the predominate reason why people moved from a London airport.[29]

Recommendations and Exceptions

Noise does adversely effect humans, and the greater the noise levels, the greater the effects. In assessing any situation in which noise is a factor, the three quantifiable effects discussed in this paper should be considered. Normally, consideration of these three quantifiable effects will provide enough information so that the severity of noise exposure can be adequately evaluated.

With this evaluation in hand, it is then proper to look at each situation and verify that some of the assumptions used in deriving the general noise descriptor are valid for that situation. Some additional statements as to whether or not there are special or unusal problems can then be made. The assumptions or considerations that might require further investigation are listed below.

1. Pure tone versus broadband noise. For the L_{dn}, the occurrence of pure tones or very narrow bands of noise will probably cause slightly more annoyance, slightly less speech interference, and slightly greater hearing loss over a narrower band of audiometric frequencies. In general, this problem can be neglected unless one is assessing sources with very dominate tones such as fog horns or attempting to reduce the noise levels by noise control.

2. Temporal pattern of the noise. While the energy averaging process usually is adequate for assessing fluctuating noise, there always is a possibility that a non-random temporal pattern of noise might correlate strongly with some activity. Such correlation could cause considerable under or over estimations of the predicted effects. For example, the noise from a race track that operated only on Sunday might cause no interference at all at an adjacent school. On the other hand, a construction yard that operated an especially loud piece of equipment from 9 to 11 each morning might cause considerable interference to an adjacent school. Assessment as to when the temporal pattern of noise might or might not be a problem will always require some good "common sense."

3. Frequency weighting. As discussed earlier, the A-weighting is a good compromise, especially when assessing the problems of all three quantifiable effects. If a very accurate assessment of a specific effect,

such as loudness or speech interference is desired, then better measures are available and in fact there are national standards for such measurements.[30,31] The A-weighting does not cover the very low frequencies (infrasound) or the very high frequencies (ultrasound). Normally these sounds are not a problem, but when such sounds exceed 105 dB, further investigation is probably needed. Information on the effects of these frequencies is available in references 8, 32, 33. The chest may also resonate from sound pressure levels above 105 dB with frequencies in the 50 to 60 Hz region, which when weighted by the A-weighting scale could result in a meter reading as low as approximately 85 dB. This rather innocuous effect might be desirable in discotheques, but could be quite annoying in other circumstances. Fortunately, these circumstances are rare.

4. Information content of noise. In developing a noise descriptor, it was accepted that different types of noises with similar L_{dn} values would be treated the same. There are definite exceptions to this. For instance the human voice may cause a problem if information can be understood. Amplified speech from a used car lot or the intrusion of a sound track of an "X rated movie" into a residential neighborhood might be good examples.

5. Impulsive noise. Sound from sonic booms, blasting, or artillery cannot be properly assessed directly by L_{dn}. Methods such as peak sound pressure level or a C-weighted L_{dn} (see ref 2) are required. The two main concerns of such noises are damage to houses and house rattling. In addition, for peak sound pressures above 140 dB, hearing loss is an additional consideration. For assessing community response from the firing of relatively small weapons

such as a skeet range, L_{dn} is probably an adequate measure. For noise induced hearing loss, the equivalent sound level should be more than adequate to assess all sounds below a peak sound pressure level of 140 dB. For impulses above 140 dB, criteria are available,[8,34] but it is my opinion that hearing protectors should be worn whenever possible.

6. Yearly averaging. As stated earlier, the yearly L_{dn} has been criticized as underestimating the effect of short time events such as a month of summer military manuevers that might expose some of the population to 75 dB. To answer this criticism, two thoughts should be kept in mind. First, some reference time period is needed if one is to avoid the problem of considering that exposure of 75 dB for a year is no worse than 75 dB for a month. While somewhat arbitrary, the yearly average will account for seasonal differences and will still restrict the level of even an exposure of a single month or a single day. For instance, the yearly L_{dn} from a month of 75 dB is 64 dB (75 dB + 10 Log 1/12). If we look at % HA, we might find that 36% of the population would be HA from a 75 dB exposure during this month. If this % HA were averaged over the year, only 3% of the population would be predicted to be highly annoyed. This 3% is probably low. While it is reasonable to expect that not as many respondents would respond as HA in December when questioned about noise that only occurred in July, some respondents will remember. The yearly L_{dn} of 64 dB would predict at least 14% of the population as highly annoyed if indeed annoyance was sampled throughout the year. This latter figure definitely seems more reasonable.

Certainly the yearly L_{dn} does not brush the noise problem under the rug. Perhaps future social studies will specially address this problem, but until then, it is my opinion that the yearly averaging which predicts a yearly annoyance of 14%, is a good compromise between assessing the yearly impact as 3% HA and 36% HA.

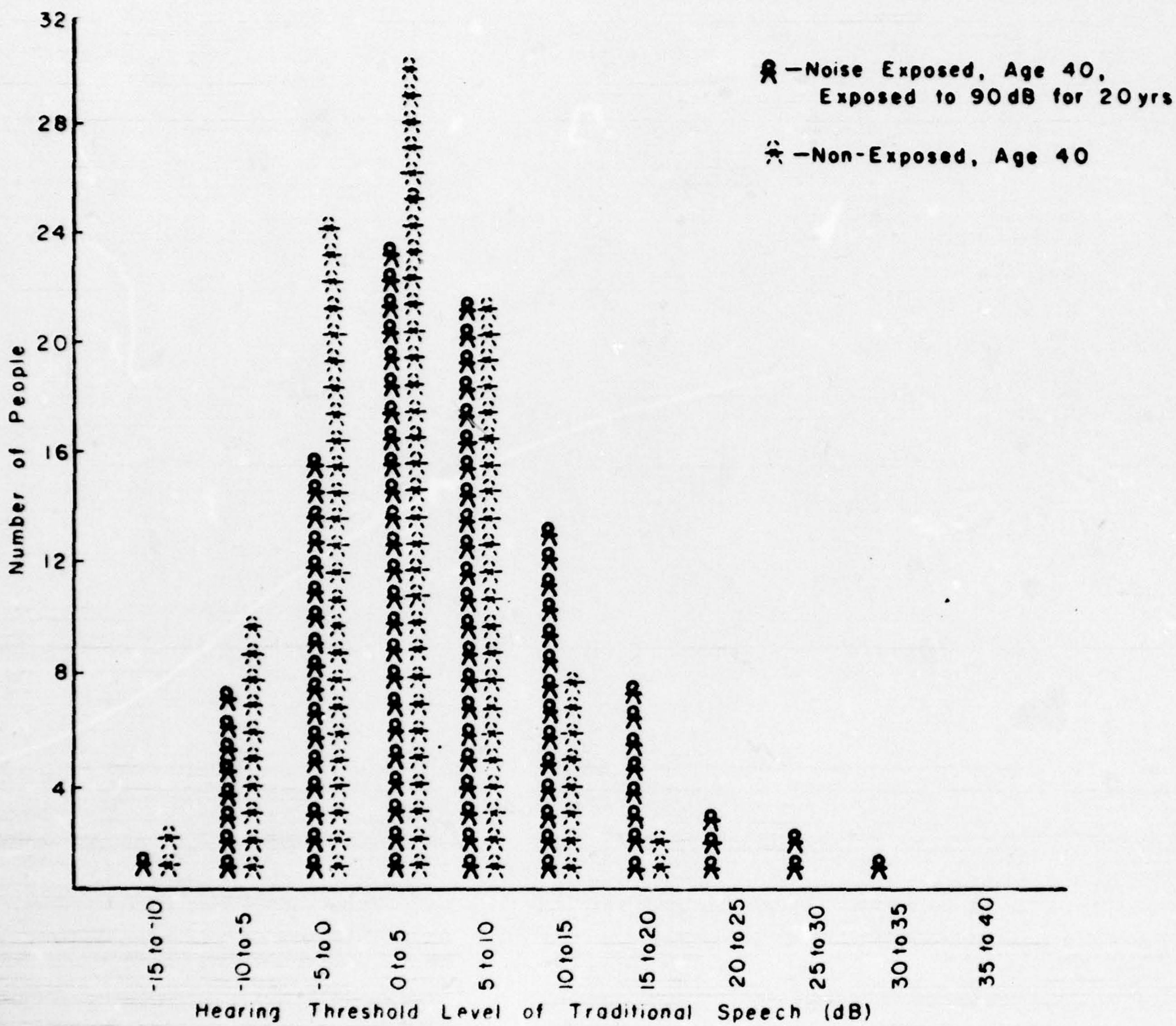
The second thought is that the limit of a daily L_{dn} can always be considered in addition to the yearly L_{dn}. From hearing loss considerations, I would suggest that an L_{dn} of 90, or an $L_{eq(8)}$ of 90, should be the upper limit of any isolated daily exposure. The current trend to use as a planning figure an L_{dn} of 65 dB nicely corresponds to limiting a single daily L_{dn} to 90 dB even if the unlikely case of the daily L_{dn} for the rest of the year were below 55 dB.

CONCLUSIONS

A useful descriptor of noise exposure is available and should always be used as the primary measure of noise exposure. Occasionally, additional measures and additional assessments of individual noise exposure situations will be required. But the additional measures should be in addition to, and not in lieu of, the basic noise descriptor. Noise exposure is complex, and it is very easy to make noise even more complex by pointing out the many imperfections in our state of knowledge and in our practices. In order to make reasonable and logical decisions on how noise affects humans, some simplications are a necessity. Using the basic descriptors L_{dn} and L_{eq}, there are three quantifiable effects that can serve as a logical basis for assessing the adversity of long term noise exposure. In response to the

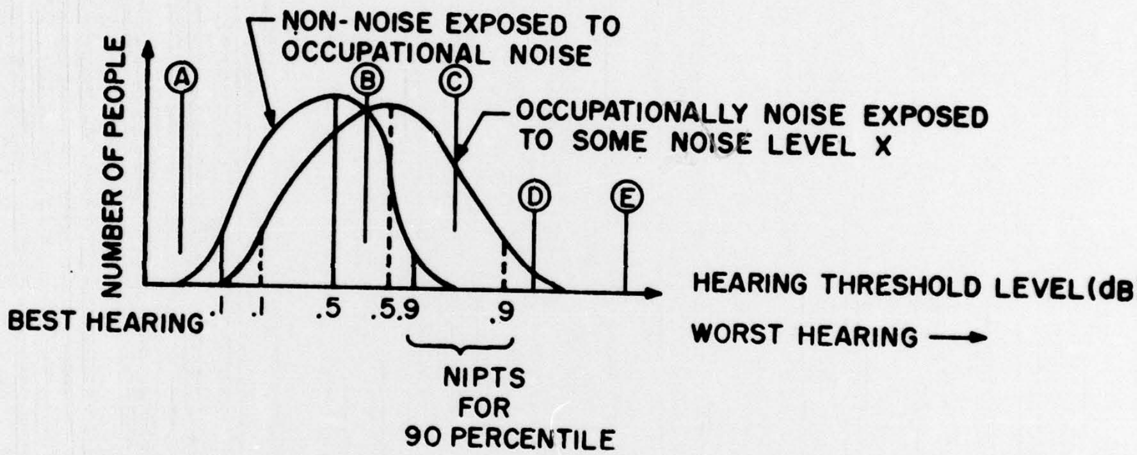
Noise Control Act of 1972, these three effects were used to identify the maximum noise levels requisite to protect public health and welfare with an adequate margin of safety. Such levels were identified in the EPA "levels document" and a summary of such levels is shown in Table 2. Economic and practical considerations might require that higher exposure levels be used in planning and regulatory decisions, but it is the opinion of the author that these lower levels serve as a useful reminder that the noise problem is a long way from being resolved.

LIST OF FIGURES

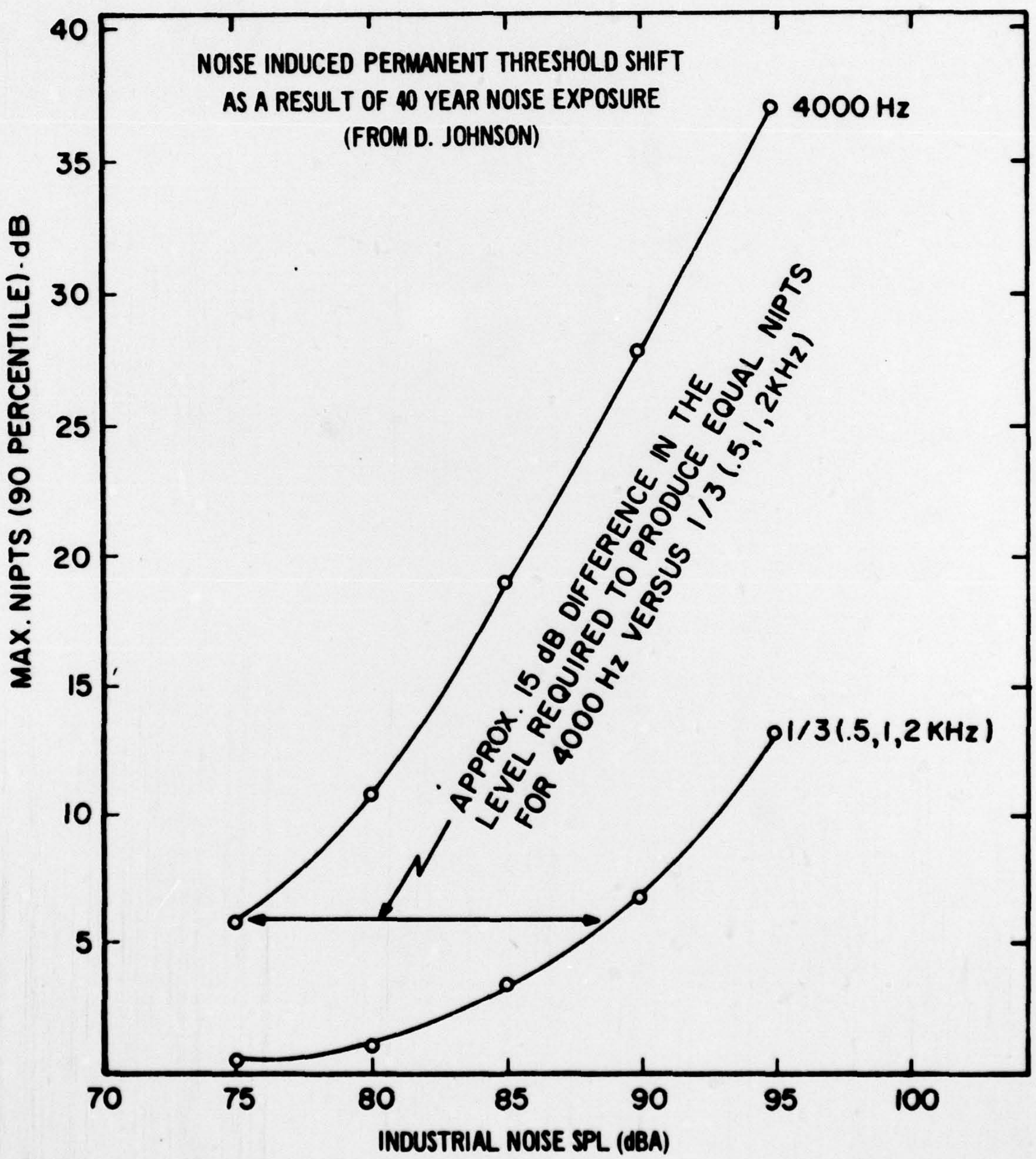


32
28
24
20
16
12
8
4
Number of People
-Noise Exposed, Age 40, Exposed to 90dB for 20yrs
-Non-Exposed, Age 40
-15 to -10
-10 to -5
-5 to 0
0 to 5
5 to 10
10 to 15
15 to 20
20 to 25
25 to 30
30 to 35
35 to 40
Hearing Threshold Level of Traditional Speech (dB)

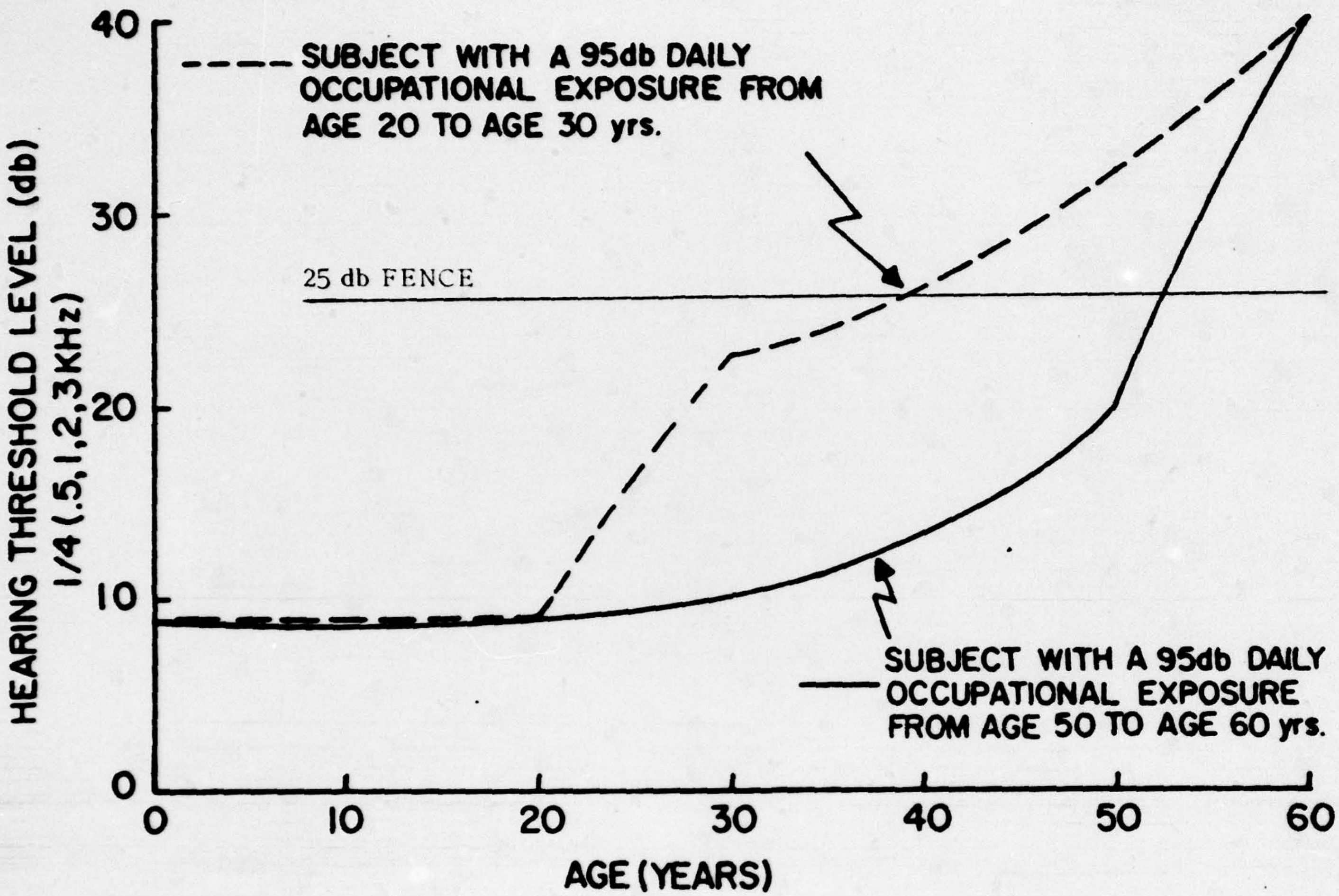
HYPOTHETICAL* CHANGES DUE TO NOISE EXPOSURE

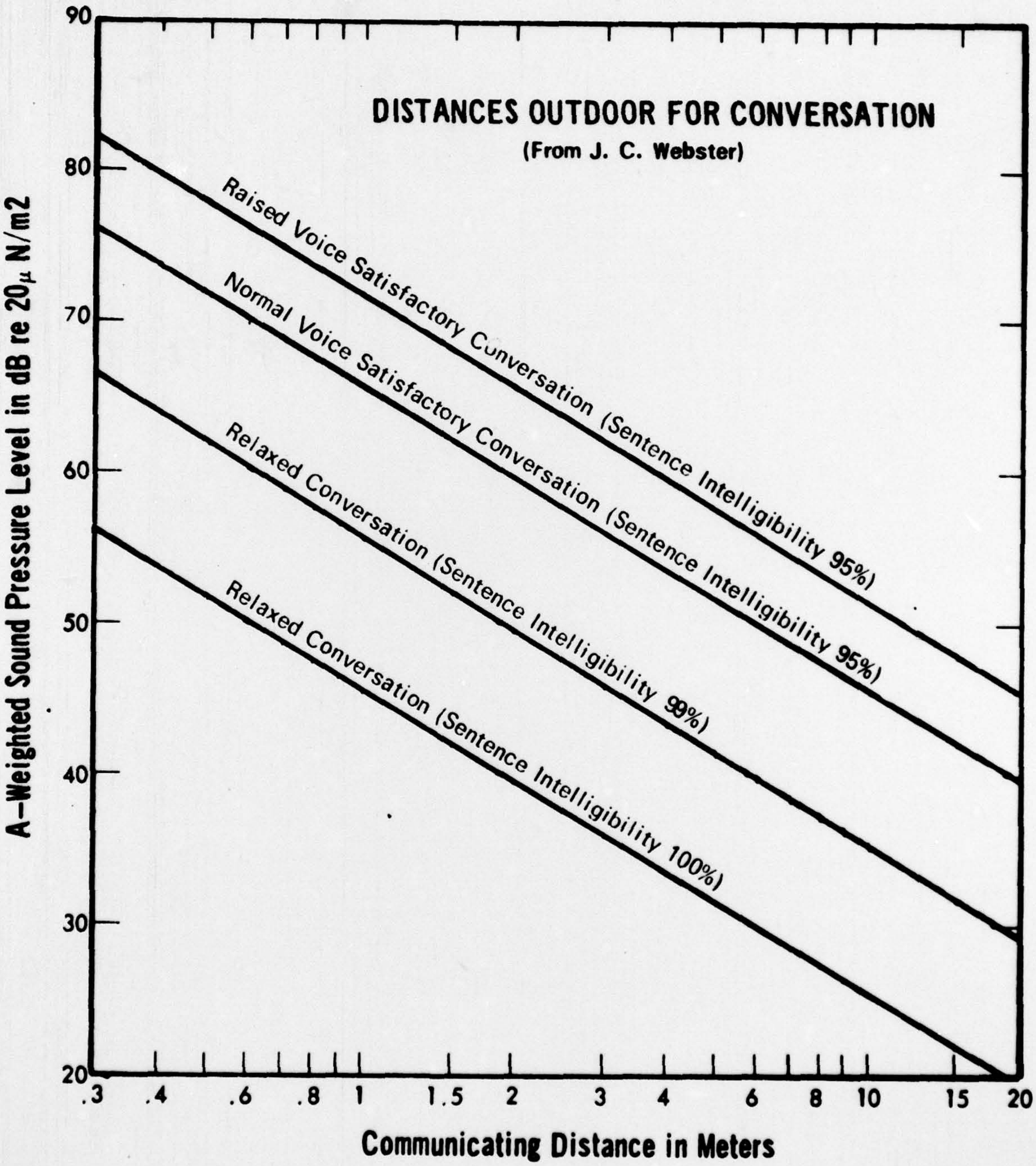


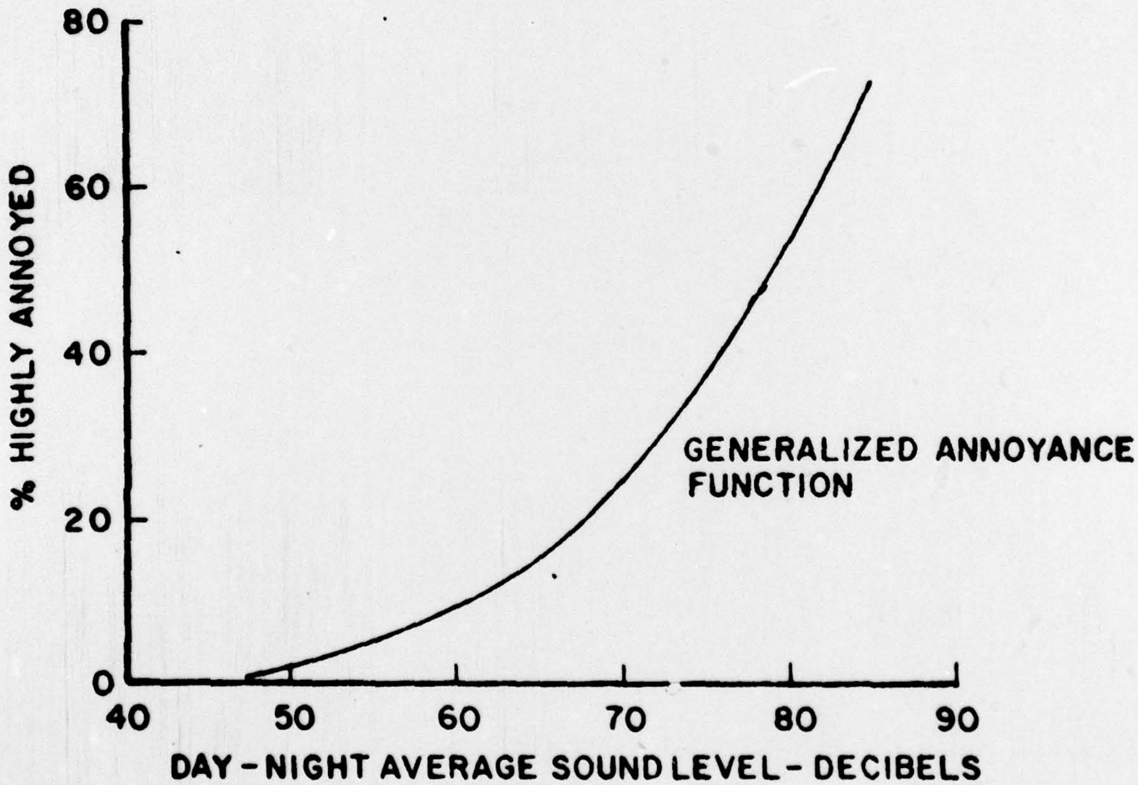
* REAL DISTRIBUTIONS MIGHT BE SKEWED OR TRUNCATED



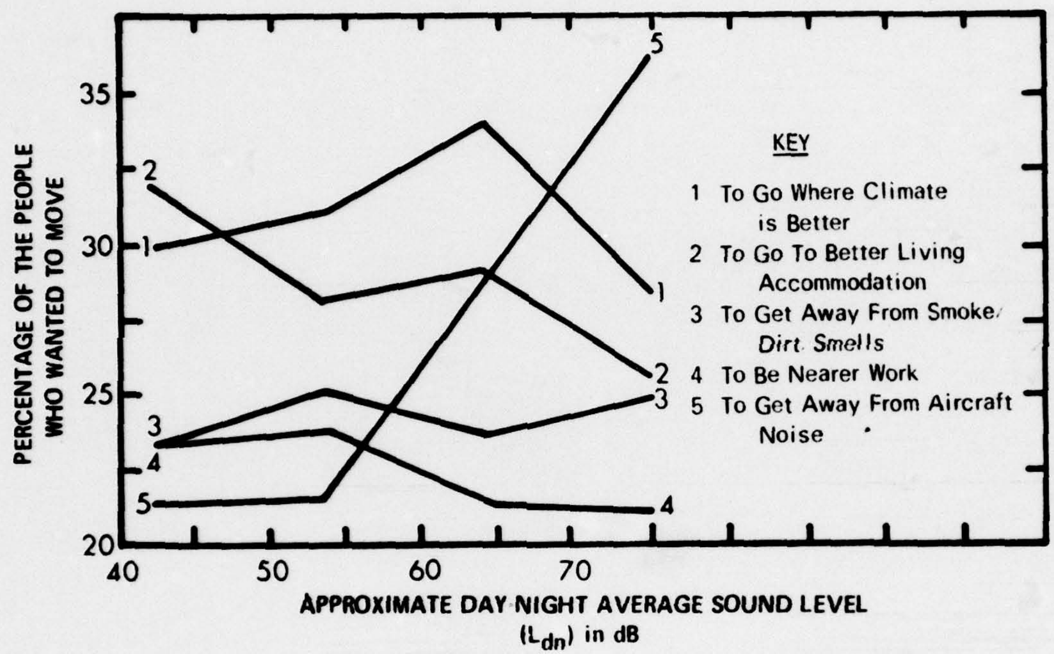
NOISE INDUCED PERMANENT THRESHOLD SHIFT
AS A RESULT OF 40 YEAR NOISE EXPOSURE
(FROM D. JOHNSON)
4000 Hz
1/3(.5,1,2 KHz)
APPROX. 15 dB DIFFERENCE IN THE
LEVEL REQUIRED TO PRODUCE EQUAL NIPTS
FOR 4000 Hz VERSUS 1/3 (.5,1,2KHz)
MAX. NIPTS (90 PERCENTILE) - dB
40
35
30
25
20
15
10
5
70
75
80
85
90
95
100
INDUSTRIAL NOISE SPL (dBA)


SUBJECT WITH A 95db DAILY OCCUPATIONAL EXPOSURE FROM AGE 20 TO AGE 30 yrs.
25 db FENCE
SUBJECT WITH A 95db DAILY OCCUPATIONAL EXPOSURE FROM AGE 50 TO AGE 60 yrs.
HEARING THRESHOLD LEVEL (db) 1/4 (.5,1,2,3KHz)
AGE (YEARS)
0
10
20
30
40
50
60


DISTANCES OUTDOOR FOR CONVERSATION
(From J. C. Webster)
Raised Voice Satisfactory Conversation (Sentence Intelligibility 95%)
Normal Voice Satisfactory Conversation (Sentence Intelligibility 95%)
Relaxed Conversation (Sentence Intelligibility 99%)
Relaxed Conversation (Sentence Intelligibility 100%)
A-Weighted Sound Pressure Level in dB re 20μ N/m2
90
80
70
60
50
40
30
20
.3
.4
.6
.8
1
1.5
2
3
4
6
8
10
15
20
Communicating Distance in Meters


80
60
40
20
0
% HIGHLY ANNOYED
GENERALIZED ANNOYANCE FUNCTION
40
50
60
70
80
90
DAY - NIGHT AVERAGE SOUND LEVEL - DECIBELS

PERCENTAGE OF PEOPLE GIVING PARTICULAR REASONS
FOR WANTING TO MOVE (London Survey 1963)



LIST OF TABLES

SUMMARY OF THE PERMANENT HEARING DAMAGE EFFECTS EXPECTED FOR CONTINUOUS NOISE EXPOSURE AT VARIOUS VALUES OF THE A-WEIGHTED AVERAGE SOUND LEVEL

75 dB for 8 hrs.

	av. .5, 1, 2 kHz	av. .5, 1, 2, 4 kHz	4 kHz
Max NIPTS 90th percentile			
NIPTS at 10 yrs. 90th percentile	1 dB	2 dB	6 dB
Average NIPTS	0	1	5
Max NIPTS 10th percentile	0	0	1
	0	0	0

80 dB for 8 hrs.

	av. .5, 1, 2 kHz	av. .5, 1, 2, 4 kHz	4 kHz
Max NIPTS 90th percentile			
NIPTS at 10 yrs. 90th percentile	1 dB	4 dB	11 dB
Average NIPTS	1	3	9
Max NIPTS 10th percentile	0	1	4
	0	0	2

85 dB for 8 hrs.

	av. .5, 1, 2 kHz	av. .5, 1, 2, 4 kHz	4 kHz
Max NIPTS 90th percentile	4 dB	7 dB	19 dB
NIPTS at 10 yrs. 90th percentile	2	6	16
Average NIPTS	1	3	9
Max NIPTS 10th percentile	1	2	5

90 dB for 8 hrs.

	av. .5, 1, 2 kHz	av. .5, 1, 2, 4 kHz	4 kHz
Max NIPTS 90th percentile	7 dB	12 dB	28 dB
NIPTS at 10 yrs. 90 percentile	4	9	24
Average NIPTS	3	6	15
Max NIPTS 10th percentile	2	4	11

Effect	Level	Area
Hearing Loss	$L_{eq(8)} \leq 75$ dB	Occupational and educational settings
	$L_{eq(24)} \leq 70$ dB	All other areas
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(8)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

REFERENCES

1. Environmental Protection Agency, "Public Health and Welfare Criteria for Noise" (1973) 550/9-73-002.

2. "Guidelines for Preparing Environmental Impact Statements on Noise," Report of CHABA Working Group #69, August 1977. National Academy of Sciences, Washington, D.C.

3. Lukas, Jerome S., "Noise and Sleep: A literature review and a proposed criterion for assessing effect," J. Acoust. Soc. Am., Vol 58, No. 6, December 1975.

   See also

   Lukas, Jerome S. Measures of Noise Level: Their Relative Accuracy in Predicting Objective and Subjective Responses to Noise During Sleep, prepared for EPA, Oct 1975.

4. Burns, William, "Physiological Effects of Noise" Handbook of Noise Control, 2nd ed., Cyril M. Harris (ed)., McGraw-Hill, NY, 1979.

5. Kryter, K. D., "Extraauditory Effects of Noise," Effects of Noise on Hearing, Donald Henderson et al (ed.), New York: Raven Press, pp. 531-546, 1976.

6. Physiological Effects of Noise, Bruce L. Welch and Annemarie S. Welch (eds.), New York: Plenum Press, 1970.

   See also

   Welch, Bruce L., "Extra-Auditory Health Effects of Industrial Noise Survey of Foreign Literature," Final Report Contract No. 16-BB-7, December 1, 1978, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

7. Henning E. von Gierke, "Noise-How Much is too Much?", AMRL TR-74-81. Noise Control Engineering, July/August 1975.

8. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA 550/9-74-004 (1974).

9. Ibid. page 10.

10. Ibid. pages A-1 to A-23

11. Robinson, D. W., "Estimating the Risk of Hearing Loss Due to Exposure to Continuous Noise," Occupational Hearing Loss, British Acoustical Society Special Volume No. 1, London and New York, Academic Press, 43-62 (1971).

12. Passchier-Vermeer, W., "Hearing Loss Due to Exposure to Steady-State Broadband Noise," Instituut Voor Gezondheidstechnjek, Sound & Light Division, Report 35, April 1968 (with supplement, 1969).

13. Baughn, W. L., "Relation Between Daily Noise Exposure and Hearing Loss Based on the Evaluation of 6,835 Industrial Noise Exposure Cases," Joint EPA/USAF Study, prepared for 6570th Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio. AMRL-TR-73-53 (1973).

14. Guignard, J. C., "A Basis for Limiting Noise Exposure for Hearing Conservation," Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio and EPA, Washington, D.C. Joint EPA/USAF Study AMRL-TR-73-90 and EPA-550/9-73-001-A (1973a).

15. Johnson, D. L., "Prediction of NIPTS Due to Continuous Noise Exposure," Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio and EPA, Washington, D.C. Joint EPA/USAF Study AMRL-TR-73-91 and EPA-550/9-73-001-B (1973).

16. Johnson, D. L., "Derivation of Presbycusis and Noise Induced Permanent Threshold Shift (NIPTS) to be used for the Basis of a Standard on the Effects of Noise on Hearing," Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH, AMRL TR-78-90 (1978).

17. Melnick, Ohio State University, personal communication.

18. Stephenson, M. R., Nixon, C. W. and Johnson, D. L. Iidentification of Minimum Level of Noise Capable of Producing an Asymptotic Temporary Threshold Shift," paper presented at the 95th Meeting of the Acoustical Society of America, Providence, Rhode Island, 18 May 1978, Vol 63, Supplement 1, spring 1978.

19. Mills, J. H., Gilbert, R. M. and Adkins, W. Y. "Auditory Effects of Long Exposures to Noise. I Temporary Threshold Shifts in Human Observers Exposed to Octave-Bands of Noise for 18-26 Hours," paper presented at the 93rd Meeting of the Acoustical Soceity of America, "Penn State University, PA, in Vol 61, Supplement No 1, spring 1977.

20. Glorig, A., "To Be or Not to Be," Sound and Vibration, Vol. 12, (1978) p. 11.

21. Ginnold, Richard, "Worker's Compensation for Hearing Loss--A Review of State and Federal Programs," University of Wisconsin, (presently in draft form).

22. National Center for Health Statistics, Hearing Levels of Adults by Age and Sex, United States, 1960-62. Vital and Health Statistics, PHS Pub. No. 1000-Series 11-No. 11. Public Health Service, Washington, D.C., U.S. Government Printing Office, October 1965.

23. The use of the four frequency average is in keeping with the latest thinking of the American Academy of Ophthalmology and Otolaryngology (AAOO). This is a change from the three frequency average of 0500, 1000 and 2000 Hz. For convincing arguments why such a change is necessary, see also ref 26.

24. A further discussion of this problem is being prepared by the author. Its preliminary title is "Investigation of the use of an Age Correction for Purposes of Compensation of a Noise Induced Hearing Loss."

25. Webster, J. C. "Effects of Noise on Speech Intelligibility," Noise as a Public Health Hazard, American Speech and Hearing Assoc., No. 4, February 1969.

See also Figure D-2 of reference 8.

26. Suter, Alice H., "The Ability of Mildly Hearing-Impaired Individuals to Discriminate Speech in Noise," AMRL-TR-78-4 or EPA 550/9-78-100, January 1978.

27. von Gierke, H. E. op cit p. 16.

28. Schultz, T. J. "Synthesis of Social Surveys on Noise Annoyance," J. Acoust. Soc. Am., Vol 64, No 2, Aug 1978.

29. "Noise-Final Report," H.M.S.O., Cmnd. 2056, London, July 1963

See also Figures D-11 and D-12 of ref 8.

30. Standard for rating Noise with Respect to Speech Intelligibility, ANSI. 14.1977, American National Standards Institute, New York, NY.

31. Computation of the Loudness of Noise, ANSI, S3.4-1968, American National Standards Institute, New York, NY.

32. Johnson, Daniel L. "Auditory and Physiological Effects of Infrasound," Inter-noise 75 Proceedings. Sendai, Japan, August 75, pp. 475-482.

33. Michael, Paul L., R. L. Kerling, G. R. Bienvenue and J. R. Prout, An Evaluation of Industrial Acoustic Radiation Above 10 kHz. Pennsylvania State University, Final report on Contract No. HSM-99-72-125, US Dept of Health Education and Welfare, National Institute for Occupational Safety and Health, Feb 1974.

34. CHABA (Ward, et al., 1968), "Proposed Damage-Risk Criterion for Impulse Noise (Gunfire)," (U). Report of Working Group 57, NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), W. Dixon Ward, Chairman, Washington, D.C. Office of Naval Research.